THE INSULATING MEDIUM SURROUNDING A CONDUCTOR THE REAL PATH OF ITS CURRENT.

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Up to the commencement of the present century our knowledge of electricity and its action was almost entirely confined to the phenomena of electric charges and their dissipation by discharge. The conception of an electric current as a steady condition of discharge had not then been clearly apprehended. It was observed that dissimilar bodies, when placed in contact with, or rubbed against, each other, manifested electric excitation. It was assumed that the electric charges thus acquired resided upon the exterior surfaces of the charged bodies, and that charged bodies evidenced mutual electric attractions and repulsions at a distance. The idea of action at a distance was, therefore, inseparably connected with early conceptions of electricity and electrical phenomena. Action at a distance was explained by some on the hypothesis that an electrified body emitted an invisible electric effluvium which acted upon electrified bodies in its vicinity. It was observed that electric charges were transmitted through certain bodies called conductors, and failed to be transmitted through other bodies called non-conductors or insulators. In a similar manner the phenomena of magnetism, as developed up to the commencement of the present century, pointed to the seeming attraction and repulsion of magnetic poles. According to the views then existing, a magnet was a skeleton of iron or steel for supporting two opposite poles at its extremities. These poles manifested peculiar properties to which the intervening skeleton was considered as merely subordinate. This magnetic action at a distance, by which the magnetic poles of the earth were assumed to direct the compass needle, was supposed by some to be effected through the medium of a magnetic effluvium emitted from the poles of the magnet. Up to the commencement of the present century, therefore, electric and magnetic phenomena were studied apart, and each was accredited with the possibility of action at a distance, except in so far as some physicists endeavored to explain such action by the intervention of material electric and magnetic effluvia. About the commencement of the present cen-

tury, the discovery of the voltaic pile brought to the notice of electricians the development of an electric current, or a steadily maintained discharge. The phenomena produced by the electric current were apparently so different from those produced by electric charges that they were at first believed to be essentially distinct. The electric current could only be produced when a complete conducting path or circuit was provided, any breach of continuity in the conducting circuit immediately interrupting the current flow. Consequently, it appeared that the electric current passed through the conductor, usually a metallic wire, in a manner somewhat similar to that in which a liquid flows through a pipe. Moreover, the electric current was apparently restricted to the conductor, and could not pass through the insulating medium surrounding it.

In 1820, not long after the discovery of the voltaic pile, Oersted announced the first known connection between electricity and magnetism. Using the usual language, when a wire, through which an electric current is flowing, is brought into the neighborhood of a suspended magnetic needle, the poles of the needle are attracted and repelled in a manner depending upon the direction of the current and its position relatively to the needle. Here an electric current apparently acted at a distance on the needle; for, in the insulating medium, usually the air, in which the magnet was suspended, no electric current could flow, and yet the magnet's poles could be acted upon at a very considerable distance from the wire carrying the electric current.

Up to the middle of the present century, therefore, the phenomena of electricity, magnetism and electromagnetic action, suggested both action at a distance, and that electric currents pass solely through the mass of a conducting wire independently of the external insulating medium. It is true that the idea of action at a distance was regarded as illogical, and as contrary to the fundamental principles of dynamics, ever since the days of Newton, but despite this unwillingness of physicists, the old notions of actions at a distance continued to be thus passively employed and promulgated, and, even to-day, they still permeate scientific literature. Another reason for the retention of the recognizedly erroneous ideas of action at a distance is to be found in the fact that, up to the middle of this century, all the mathematical processes adopted for dealing with the phenomena of electricity, magnetism and electromagnetic action, tacitly assumed the principles of action at a distance just as

the mathematical processes of astronomy at the present time tacitly assume the same law, without pretending to explain the mechanism by which such action may be conveyed. Consequently, it was only too easy for students to imbibe, with the mathematical ideas for studying quantitative electromagnetic facts, the fundamental hypothesis of action at a distance upon which this idea was based. Thus the mechanical forces existing between charged electrified bodies, between magnet poles, between electric currents, or between electric currents and magnets, were all referred to the mutual actions of elementary portions of imaginary electric or magnetic substances, each of which exerted an influence proportional to its quantity, and inversely proportional to the square of its distance from the element acted on. About the middle of the present century, Faraday first paved the way for a change in our views on these questions. He suggested the theory that an electrified body or a magnet did not emit any material effluvium, but exerted an influence on the invisible medium in its vicinity; namely, the universal ether; that this influence was of the nature of a stress, and that the ether surrounding an electrified or magnetized substance was in some manner strained along certain directions which he called lines of force. Consequently, an electrified body produced lines of electric force along which the ether was strained, while a magnetized body similarly produced lines of magnetic force along which the ether was strained, but in a manner different from electric strain. It was this strained ether that connected the electrified or magnetized bodies with bodies in their neighborhood, and permitted attraction and repulsion to be set up between them without necessitating any action at a distance.

Clerk Maxwell developed the ideas of ether strains and stresses mathematically. While retaining the original methods of quantitatively determining the mechanical actions between electric and magnetic bodies, by summing up the effects of all the elements of those bodies on each other, in reference to the inverse squares of the distances, he developed, at considerable length, the action of the intervening medium, and showed how the strain in such medium could produce the mechanical effects observed. In the treatment of this subject he noticed that a disturbance of the electric or magnetic condition of the ether was controlled by a formula similar to that which controls a disturbance in an elastic solid. He was, therefore, led to believe that electromagnetic disturbances in the

ether were propagated in all directions like disturbances in an elastic solid, and were, therefore, transmitted in waves. Maxwell, therefore, was the discoverer of the probability of electromagnetic waves in ether. He also suggested that light might be a purely electromagnetic phenomenon of very high frequency, and adduced experimental evidence in favor of this belief. The actual existence of these electromagnetic waves has since been abundantly demonstrated by Hertz and many others. Though invisible to the unaided eye, electromagnetic waves can be traced by the aid of sensitive electromagnetic apparatus constituting what has not been inaptly styled the electric eye.

As the result of both the experimental and mathematical work of the latter half of the present century, especially that of Mr. Oliver Heaviside, it is now believed that electric currents are transmitted as electric waves through the ether surrounding a conductor, being guided by the conductor, but not transmitted through it.

Notwithstanding the fact that the more modern views have been in existence for upwards of thirty years; that their truth is practically undisputed, and that, on the contrary, within the last ten years, strong experimental evidence has been adduced in their behalf, yet both the old phraseology and the old methods of treatment are still almost universally employed even in the modern text-books of the day.

In view of the preceding facts, the authors consider that a brief description of the manner in which an electric current is now believed to be transmitted, may aid in disseminating the more modern views.

All electric, magnetic or electromagnetic phenomena are now believed to be referable to two conditions of stress in the ether, one of which is called *electric flux*, and the other, *magnetic flux*. The exact nature of both is unknown. Though invisible, the presence of each may be manifested in a variety of ways. So intimately are the electric and magnetic fluxes correlated, that any disturbance in one immediately calls the other into existence. Electric flux exists between two electric charges. Thus, a positively charged sphere, situated at rest in a room, radiates streams of electric flux, towards all parts of the room, along lines called *stream lines*, which may be readily mapped out. The ether is strained or disturbed in some manner along these stream lines. So long as the charge on the insulated body remains at rest, electric flux will per-

meate the air and ether in the room, but there will be no magnetic flux present, except that due to the earth's magnetism. As soon, however, as any motion occurs in an electric flux, either by moving the charge on the body, or by causing it to increase or decrease in density, the disturbance in electric flux temporarily produces a magnetic flux; and, generally speaking, any variation or motion of electric flux produces magnetic flux.

A permanent magnet produces magnetic flux, both in its substance and in the space surrounding it. So long as the distribution of magnetic flux remains quiescent, no electric flux is produced. As soon, however, as any change takes place in the magnetic flux, either by bodily moving the magnet, or by weakening or strengthening the magnet, electric flux is temporarily produced. Generally, any variation or motion of magnetic flux produces electric flux.

Magnetic flux is always circuital, or is distributed in stream lines which form closed curves, or have reëntrant paths. Electric flux, when established between opposite electric charges, is not circuital, but terminates at one end in one charge, and at the other end in the opposite charge. When, however, electric flux is established by magnetic disturbances in a space free from conductors, it is circuital, like magnetic flux.

Both electric and magnetic flux possess both direction and polarity; that is to say, each is developed along definite stream lines, and each possesses different properties up and down such stream lines. An analogy is presented mechanically in a stream of water. Water in a river flows in stream lines, and is directed in its motion down stream. In the case of electric flux the polarity is manifested by what are called positive and negative charges, these charges being developed where the electric flux terminates. In the case of magnetic flux the polarity is manifested by what is called north-seeking poles and south-seeking poles. These poles are developed where the magnetic flux terminates on the magnet. For this reason electric flux is conventionally assumed to leave a positive charge and, to terminate, on arrival at a conductor, at a corresponding negative charge. This, while being a purely arbitrary assumption, is, nevertheless, advantageous in fixing ideas. Similarly, magnetic flux is assumed to issue from a magnet at its north-seeking pole and to reënter it at its south-seeking pole. This assumption is also purely arbitrary.

Both electric and magnetic fluxes contain energy. Work must be charged on the flux to establish it, and this work is liberated when the flux disappears. The energy in the ether varies as the square of the flux density, so that if we crowd uniformly twice as much flux through a given area of cross-section, we quadruple the amount of energy which resides in that portion of space per cubic inch, or per cubic centimetre.

The electric transmission of power consists in transferring electric and magnetic flux to a distance and allowing these fluxes to be expended in liberating, at the receiving end of the line, the energy they contain. An electric generator is a machine for producing electric flux and thus transferring electric energy to the ether. This electric flux, or energized condition of the ether, is transferred to a distant point along wires, the ether being deprived of its energy at the receiving end of the line. The electric flux is there absorbed, and the work which was expended by the generator is recovered to a greater or less extent.

The electric flux is transmitted from the generator to the receiver, through an insulating medium, being guided on its passage by a pair of conductors, extending all the way from the generator to the receiver. Such a pair of conductors, with the associated insulating medium between them, is called an *electric circuit.* The curious fact exists that while the old conception of an electric circuit held that the electric current passed through the conductors, and was retained in position on those conductors by reason of the insulating medium surrounding them, the modern view holds, on the contrary, that the electric current flows through the insulating medium and is held in position, or guided to its destination, by the two conductors. In other words, the modern theory completely reverses the relative functions of the insulator and the conductors in the old theory.

There are three standard types of pairs of conductors, and their associated, intervening, insulating medium; viz.,

1. An aërial conductor, such as a telegraph wire, supported sensibly parallel to the surface of the ground. Here the wire forms one conductor, the ground the other conductor, while the ether associated with the air between them is the medium through which the electric current flows.

2. Subterranean or submarine conductors separated from the surrounding conducting earth or water by a uniform layer or coating of insulating material. Here one conductor is formed by the

interior wire, while the other conductor is the sheath of metal, liquid or ground, and the medium through which the electric current flows is the ether in the insulating coating of rubber, gutta-percha, paper, etc., with which the interior conductor is invested.

3. A pair of overhead wires supported sensibly parallel to each other, on suitable insulating supports; as, for example, a pair of telephone or electric-light conductors. Here the two wires are the conductors, and the medium through which the electric current flows is the ether in the air between them.

When an electric source is connected to any such pair of conductors, an electric flux is established in the insulator between them; or, more correctly speaking, in the ether permeating the insulator. The density of the electric flux, or the quantity of flux per normal square centimetre, will depend upon the nature of the insulator, on its dimensions, and on the electric pressure or voltage of the source. An increase of voltage is attended by a proportional increase in the density of the electric flux; while an increase in the thickness of the layer of insulating material between the conductors diminishes the density. Figs. 1, 2, 3, are diagrams of the distribution of electric flux for the three types of circuit mentioned.

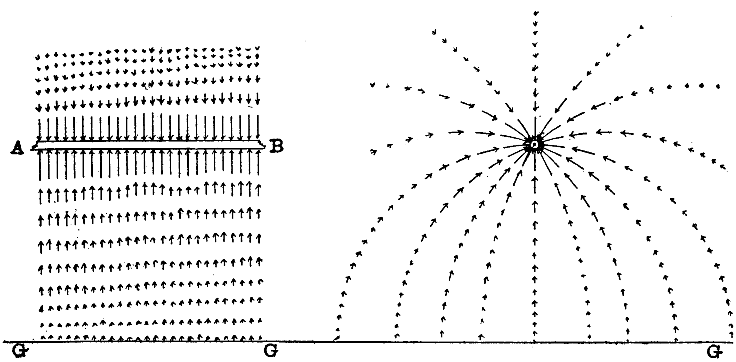


FIG. 1.—Electric Flux Surrounding an Aërial Wire with Ground-Return Circuit.

In Fig. 1, AB, represents the aërial wire, and GG, the ground. The flux stream-lines are represented on the right-hand side in a plane perpendicular to the wire. These stream lines are arcs of circles, on the supposition that the ground, GG, is conducting, and has a level surface, such as might be presented by the surface of water in a lake. On the left-hand side the flux is represented as

being distributed in straight lines; *i. e.*, in sections of planes, perpendicular to the wire and to the ground. The wire being negatively charged, by convention the flux streams converge towards it.

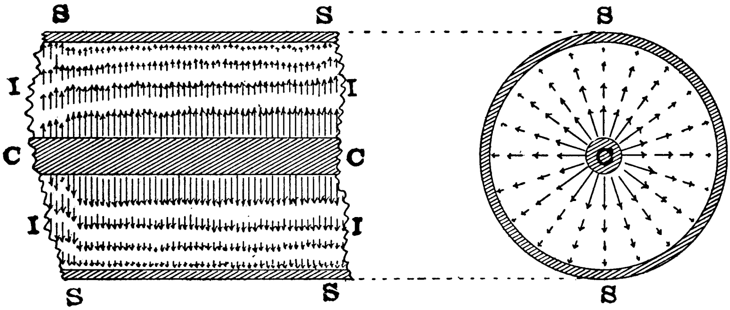


FIG. 2.—Electric Flux Permeating Insulator of Cable.

In Fig. 2, CC, is an insulated conductor, usually of copper, separated from the conducting sheath SSSS, which may be of lead or other metal, by the cylindrical insulating jacket IIII. Here the flux is represented as emerging from the wire which is, therefore, regarded as positively charged. The density of the flux is greatest in the vicinity of the interior conductor, and diminishes uniformly as we proceed towards the sheath. This is represented diagrammatically by the length of the flux arrows. On the left-hand side the flux is seen to be distributed in planes perpendicular to the length of the cable.

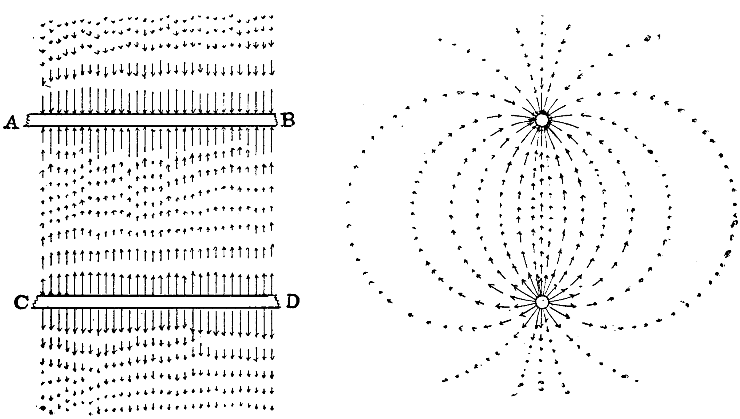


FIG. 3.—Electric Flux Permeating Insulator between Two Parallel Wires.

Fig. 3, represents two parallel wires, AB and CD, the latter positively and the former negatively charged. Here the flux issues from the wire CD, and converges upon the wire AB, in curves, which are all arcs of circles. The flux density is greatest in the neighborhood of each wire and least in the intermediate portions. On the left-hand side, the longitudinal section shows that the flux is distributed uniformly in planes perpendicular to the two wires.

The electric flux, which thus permeates the insulating medium, persists as long as the insulation is maintained, even in the absence of the original electric source. Thus, if a pair of wires be perfectly insulated from each other, and are charged as represented in Fig. 3, by connection to an electric source; then, so far as is known, the electric flux, which will be developed between them in the insulating medium, will be indefinitely maintained, although in practice there is always sufficient leakage to permit the charge to gradually disappear.

In order to study the electric transmission of power over a circuit, we may suppose that a pair of perfectly conducting wires exists extending between two cities. These conductors may be, say, of the third type; *i. e.*, may consist of a pair of parallel wires supported in air. Let AB and CD, Fig. 4, represent such a pair of conductors

Fig. 4

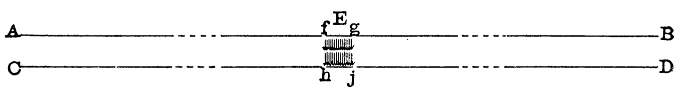


Fig. 5

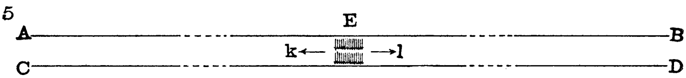
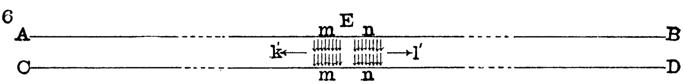


Fig. 6



FIGS. 4–6.—Movement of Electric Flux in Circuit of Perfect Conduction and Insulation.

between the terminal stations AC, on the left hand, and BD, on the right. At the middle of the line E, we may suppose that suitable

short lengths of each of the two wires; namely, fg and hj, each one metre long, are insulated from the rest of the system, and electrically charged by a momentary connection to a dynamo or other suitable source, to a pressure of say, 1000 volts. An electric flux will thus be established between the two short lengths of wire of the type represented in Fig. 3, and shown in Fig. 4, by the arrows; fg, being positive, and hj, negative. Strictly speaking, the flux disturbance would not remain in parallel planes at the ends of the short lengths, but would bulge outwards considerably, from the ends; but this peculiarity is of no consequence to what follows, and we may, therefore, suppose that the simpler geometrical distribution is preserved. If the metre lengths at E, be perfectly insulated from each other, the block of electric flux resident in the ether between them would be indefinitely maintained at 1000 volts pressure.

Suppose, however, that at some instant of time the discontinuities existing between the metre lengths of the conductors and the rest of the system are suddenly bridged over. In other words, the metre-lengths are connected electrically at both ends to the rest of the circuit. Then instantly the flux tends to rush towards the ends of the circuit as represented by the arrows k and l, in Fig. 5. The metre block of flux instantly subdivides into two metre blocks, each under 500 volts pressure, and each with half the original density and, therefore, one-quarter of the original energy. At the same time, the moment that the flux commences to run, a magnetic flux distribution is brought into existence; for, as we have already mentioned, a motion of electric flux can never occur without producing magnetic flux. While then the metre block of Fig. 5, divides into two separate metre blocks, moving in opposite directions, as in Fig. 6, each block becomes invested with magnetic flux in the manner represented in Fig. 7. Here the curves of magnetic flux distribution, indicated by arrows, are circles eccentric to the wires. One-half the energy of each moving block is electric and is resident in the electric flux, and one-half is magnetic and is resident in the magnetic flux. It will be observed that the magnetic flux is so directed as to pass through the loop formed by the two wires, in planes perpendicular to the wires. Moreover, the curves of magnetic flux stream-lines are all perpendicular to the curves of electric flux stream-lines, which, already shown in Fig. 2, are here represented by dotted lines. The magnetic flux at each point is due to the movement of the electric flux through the ether at that point,

and is not due, as the old theory supposed, to an assumed current in the wire. The passage of the electric flux over the wires constitutes a momentary electric current, which in this case would have a strength of roughly two amperes. The velocity with which the flux blocks move in Fig. 6, is the velocity of light in air; approximately, 300,000 kilometres per second. If the distance from E, to the ends of the wires is exactly 300 kilometres each way, the metre blocks of

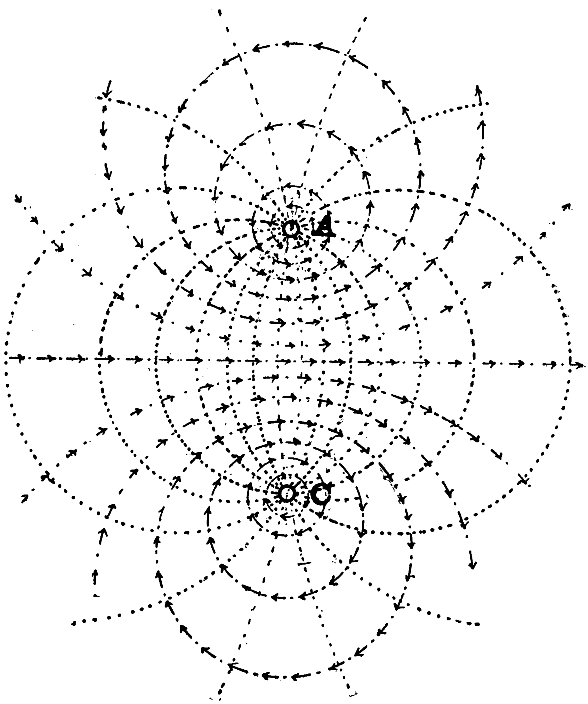


FIG. 7.—Magnetic Flux Accompanying Moving Electric Flux between Two Parallel Wires.

flux will traverse this distance in $\frac{1}{1000}$th of a second. The metre blocks will, therefore, pass by any particular point on the line in $\frac{1}{300,000,000}$th of a second, and the electric current, which this flux rush constitutes, would, therefore, have this duration at any particular point.

Fig. 8, represents the metre blocks of flux in the act of arriving at the termini of the line. The two conductors are open-cir-

cuited, or insulated, at both ends. The arrows v and v′, represent the direction in which the blocks have arrived, and the curved arrows mm, and m′m′, represent the direction of magnetic flux which has been generated by the movement of each block, and which has been carried bodily along with the moving blocks. If the original metre block of flux in Fig. 4, represents an amount of energy resident in electric flux, amounting to say 1000 ergs, then each of the two metre blocks into which this is divided, assuming no dissipation of energy, carries with it 500 ergs, 250 in magnetic flux and 250 in electric flux.

Fig. 8

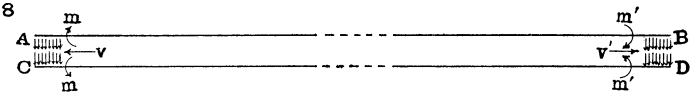


Fig. 9

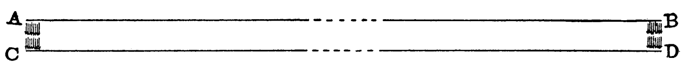
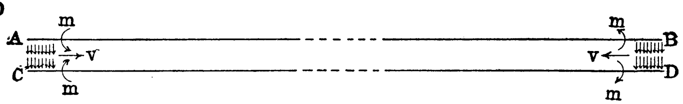


Fig. 10



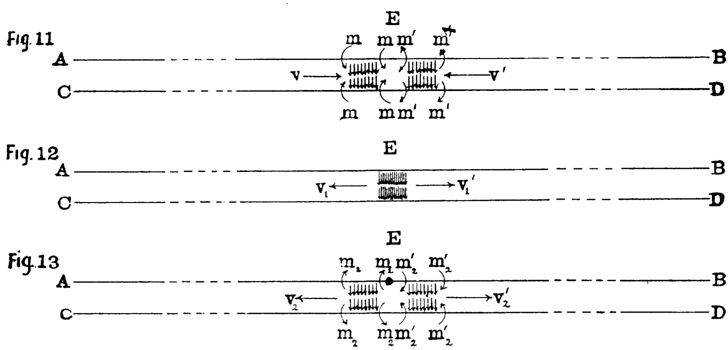
FIGS. 8–10.—Reflected Movement of Electric Flux in Circuit of Perfect Conduction and Insulation.

On arrival at the termini, the flux is compressed into a half metre at each end, as represented in Fig. 9. The density of electric flux is doubled, as represented by the closeness of the arrows. At the same time the magnetic flux vanishes, while the pressure rises momentarily from 500 to 1000 volts. There is, therefore, half the volume of flux with twice the density; and, therefore, four times the voluminal electric energy, but no magnetic energy. Consequently, there remains 500 ergs of purely electric energy in each block.

Fig. 10, represents the conditions of affairs immediately afterwards. Here the blocks expand again into metre lengths and are reflected from the termini, or move back towards the centre of the line. The magnetic flux reappears, but in the reversed direction, as shown by the curved arrows. The electric flux retains its original direction from the upper to the lower wire, and the pressure has fallen from 1000 to 500 volts as before. The current represented

by the flux rush is, therefore, reversed in direction, since the magnetic flux, by which it is measured, is reversed, but the electric potential difference, as measured by the density of electric flux, remains unaltered. The two metre blocks now rush towards the centre of the line with the speed of light. They may be considered as solitary waves of light, that is to say, disturbances traveling with the velocity of light waves, but not periodic, and leaving the medium quiescent the moment they pass by.

After the lapse of another $\frac{1}{1000}$th of a second, the two metre blocks, which will again arrive at E, the middle of the line, as shown in Fig. 11, where the two arrows v and v′, indicate that the blocks are about to collide. The curved arrows show that the magnetic flux is oppositely directed in the two blocks, those on the left-hand side at mm, being directed into the loop, as seen by the observer, while those on the right-hand side at m′m′, being directed out of the loop.



FIGS. 11–13.—Collision of Electric Flux Waves in Circuit of Perfect Conduction and Insulation.

In Fig. 12, the metre blocks are represented as having collided; they have merged together and mutually annulled each other's magnetic flux. Consequently, there is no magnetic energy. On the other hand, the density of electric flux being doubled, there will be four times the electric energy per cubic centimetre. Consequently, there are 1000 ergs of electric energy in the single metre block at 1000 volts pressure, just as in the original condition before the start, in Fig. 5. The two blocks, however, pass completely through each other, appearing on the opposite sides.

Fig. 13, represents this condition of affairs. Here the two blocks have passed completely through each other and once more rush out with the velocity of light towards the ends of the conductors, which they will reach in the $\frac{1}{1000}$th of a second. This process of meeting in the centre, separating, reaching the ends, and being reflected therefrom, will repeat itself indefinitely in cycles which take $\frac{4}{1000}$th of a second to complete, the current direction reversing at each reflection from the ends. In this case of perpetual motion, we have assumed that there is no dissipation of electromagnetic energy, there being no leakage between the two conductors, and perfect conduction in the two wires.

We have hitherto assumed that the two wires AB and CD, were open-circuited, that is insulated from each other at their termini. We now suppose that they are short-circuited; that is directly connected at the termini. Let the metre block of flux be started from E, the centre of the line, as in Fig. 5. Then, in $\frac{1}{1000}$th of a second, the two metre blocks, into which the original block divides, will rush over the intervening 300 kilometres, and will reach the ends of the line as shown in Fig. 14, the arrows v and v′, indicating the direction in which the blocks have arrived, and the curved arrows representing the direction of accompanying magnetic flux. In this case, instead of the electric density being doubled, the electric flux vanishes completely as soon as the magnetic flux is compressed into half a metre of length. The magnetic flux is, however, doubled in density, as represented by the doubled curved arrows of Fig. 15. Here the energy is all magnetic, and each half-metre block of magnetic flux at the ends of the line contains 500 ergs of energy.

Fig. 14

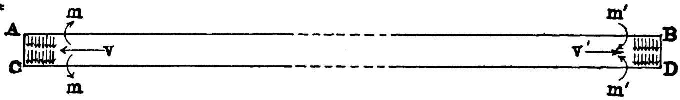


Fig. 15

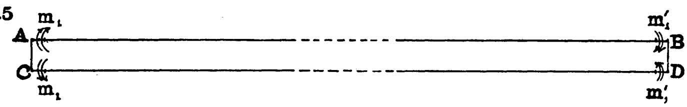
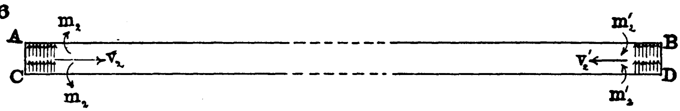


Fig 16



FIGS. 14–16.—Reflected Movement of Electric Flux in Circuit of Perfect Conduction and Insulation, Short-Circuited at Termini.

Fig. 16, represents the condition of affairs the moment after the disappearance of electric flux. Here the electric flux has reappeared in the form of the two metre blocks, which take their departure towards the centre of the line, but now it will be observed, by the direction of the flux arrows, that the electric flux is reversed in direction. Consequently, the lower wire has become positive and the upper wire negative; or, the 500 volts difference of potential between the wires is reversed in direction by reflection from the short circuits at the termini. The magnetic flux possesses its original direction as shown by the curved arrows. Consequently, the momentary current, which is constituted at any point along the line by the flux rush past it, does not change direction when the pulse comes back reflected.

The two reflected metre flux-blocks rush with the speed of light towards the centre of the line. The condition of affairs just before they meet is represented in Fig. 17. The magnetic flux is oppositely directed in the two blocks. Consequently, when the two blocks merge, as shown in Fig. 18, the magnetic flux is annulled, but the electric density is doubled. We have, therefore, in Fig. 18, 1000 ergs of energy in electric flux, situated in a metre block, but with the opposite direction of potential to that which exists in the original state of Figs. 4 and 5.

Fig. 17

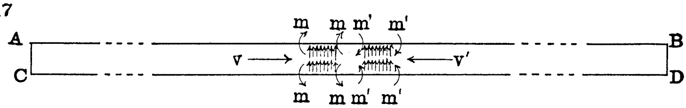


Fig. 18

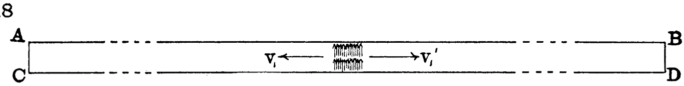
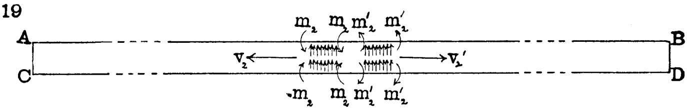


Fig. 19



FIGS. 17–19.—Collision of Reflected Electric Flux Waves in Circuit of Perfect Conduction and Insulation Short-Circuited at Termini.

The two metre blocks then separate out by passing through each

other as shown in Fig. 19, where the two blocks are seen to be withdrawing from each other with the speed of light. They again rush to the termini of the line, where they undergo reflection with reversal of electric flux and persistence of magnetic flux. This condition of reflection and collision would continue forever, under the conditions assumed.

We have hitherto assumed that the insulator insulated perfectly and the conductor conducted perfectly. Neither of these two conditions is attained in practice. We will first assume that there is imperfect insulation in the insulator, with perfect conduction in the wires. For convenience, we may change the type of circuit to the second; namely, a cable composed of a central wire and annular external conducting sheath. This is represented in Fig. 20,

Fig 20

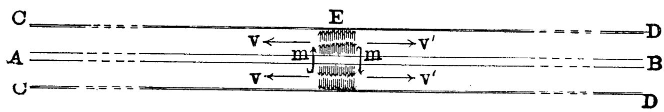


Fig. 21

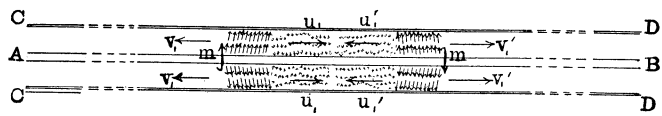
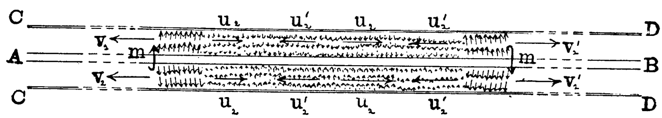


Fig. 22



FIGS. 20–22.—Movement of Electric Flux in Cable of Imperfect Insulation and Perfect Conduction.

where AB, is the central conductor and CD, CD, the external conducting sheath. Let us suppose that a metre block of flux, at 1000 volts, is, as before, called into existence, and released from the centre of the line. The flux block immediately starts with the velocity of light in the ether of that particular insulator, which may be, perhaps, 200,000 kilometers per second, instead of 300,000 kilometers per second, as in free ether. The block, as before, subdi-

vides into two metre blocks, each with half the density and each with its attendant magnetic flux, as represented by the straight and curved arrows of Fig. 21. Instead, however, of pursuing their paths as sharply defined blocks, the two blocks are subjected to attenuation by leaving stragglers or remnants along the road, since the insulator is somewhat leaky. That is to say, the path through which they pass is strewed with reflected or oppositely directed electric flux, of reduced density, which immediately turns around and moves back towards the centre of the line with the velocity of light in that medium. Consequently, the two metre blocks undergo a process of decay; their density is diminished; their energy is dissipated in the insulator as heat, and in supplying the straggling reversed fluxes; and the distribution, instead of being in planes perpendicular to the cable, is bent backwards in a manner which is exaggerated in Fig. 21. In fact the flux behaves as though it got entangled in the insulator instead of moving freely through it, and by reason of the entanglement, a number of shreds or straggling particles are detached from the advancing main body. If the leakage be sufficiently great, the blocks of flux may be completely dissipated before they arrive at the termini of the line, the degree of attenuation depending entirely upon the amount of leakage.

Fig. 22, represents the condition of affairs at a later stage of the first outward movement of the flux blocks. Here v_2 v'_2, represent the movement of the heads of the columns; u_2 and u'_2, represent the backward movement of the stream of stragglers thrown off by the heads in the course of their motion. Consequently, the entire field between the two separating heads is filled with a confused and straggling mass of attenuated flux, and a very complex state of affairs is reached. The original blocks are entirely absorbed after they have traveled a greater or less distance.

We may next assume that the insulator insulates perfectly, but that the wires do not conduct perfectly. This is a condition which is very nearly represented in many practical cases. In Fig. 23, the metre block of flux starts from the centre as before. The interior conductor being positively, and the sheath negatively, electrified. The curved arrows represent the direction of accompanying magnetic flux, produced as soon as the motion takes place. Here the imperfect conduction of the wire sets up a series of straggling reflections of electric flux, in the same direcion, however, as that in the moving blocks, instead of the oppo-

site direction, as in Figs. 21 and 22. The electric flux is bent from the perpendicular in the direction of motion, as represented in exaggeration at Fig. 24. Consequently, the metre blocks are subjected to a process of attenuation or decay, by throwing off attenuated electric flux as they advance, the straggling flux so thrown off immediately commencing to rush backwards with the velocity of light in the medium as represented by the arrows u_1 u'_1. The metre blocks, therefore, lose definition as they advance, becoming weaker and weaker, the energy being lost into the conductor and into straggling flux. If the wires conduct sufficiently imperfectly, the two metre blocks may be completely absorbed before they reach the terminals of the line, the degree of attenuation depending entirely upon the degree of imperfection in conducting power, for a given electric cable; *i. e.*, a given geometrical distribution of insulating medium. The fact of imperfect conduction, may be represented roughly by supposing that the flux, instead of slipping freely along the surface of the conductor, becomes entangled in the surface of the same, and friction between the base of the moving flux and the surface of the wire detaches some of the flux and leaves the detritus in the pathway.

Fig. 23

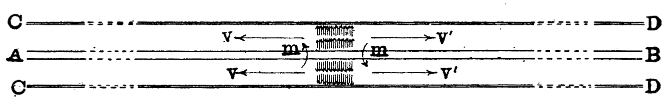


Fig. 24

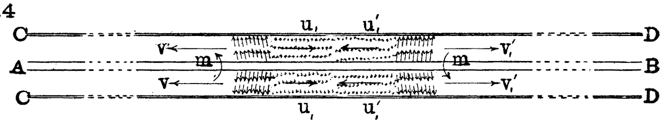
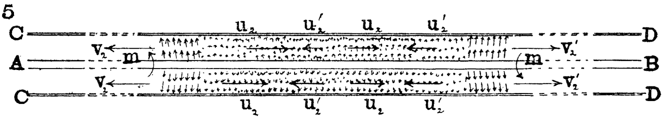


Fig 25



FIGS. 23–25.—Movement of Electric Flux in Cable of Perfect Insulation and Imperfect Conduction.

Fig. 25, represents the condition of attenuation at a later stage.

Here the original metre blocks have diminished considerably in density, and in their stock of energy, their motion being indicated by the arrows v_2 and v'_2. u_2 and u'_2, are arrows representing the motion of the straggling flux, or *tails*, as they have been called, thrown off by the advancing blocks. After a certain distance has been traversed by these blocks they become completely absorbed and the tails only remain, the subsequent motion being very complex.

All the best electric conductors with which we are acquainted; namely, the metals, conduct imperfectly at the temperatures at which they exist on the earth. It has been shown that pure copper would apparently conduct to perfection, or have no electric resistance, at the temperature of absolute zero, or — 273° C. It is possible that some means may eventually be found to artificially produce in copper, at ordinary temperatures, the electric conducting power it possesses at or near the absolute zero of temperature, but at the present time we have to content ourselves with the comparatively imperfect conducting power of copper, which is practically the best electric conductor available. Consequently, we cannot attain in practice to the distortionless transmission of electro-magnetic waves such as represented in Figs. 4 to 19.

It is, however, possible to so unite imperfect insulation with imperfect conduction; *i. e.*, leakage with conductor-resistance, as to cause the tailings due to leakage to exactly annul the tailings due to conductor resistance; for, the comparison of Figs. 20, 21 and 22, with Figs. 23, 24 and 25, will show that these tailings are oppositely directed as regards electric flux, the tailings from leakage being reversed, and the tailings from conductor resistance being similarly directed, to electric flux in the main blocks. A circuit in which the leakage and conductor resistance are so balanced as to leave no tailings, is called a *distortionless circuit*, and no other means of obtaining a distortionless circuit is known at the present time. Although such a circuit is distortionless, since no tailings are left, as the blocks of flux move on without leaving stragglers, yet energy is expended both into the insulator and into the conductor, and, consequently, the fluxes diminish in density and attenuation goes on. This is represented in Fig. 26. Here the metre block of flux is started from the centre of the line as before, the directions being indicated by the arrows. In Fig. 27, the electric flux is seen to have a double curvature, being partly bent outwards and partly bent inwards. Energy is being dissipated sideways into the insulator,

and sideways into the conductor, as the blocks move on. Consequently, the electric density and the accompanying magnetic density are diminishing, but no straggling electric or magnetic flux is left to mark the passage of the blocks. If the original stock of energy was 1000 ergs, the energy which may reside in the two blocks, when they reach the ends of the line, may be, perhaps, only 100 ergs, depending entirely upon the amount of electric resistance in the conductor, and the corresponding amount of leakage which must be given to the insulator in order to balance the same.

Fig. 26

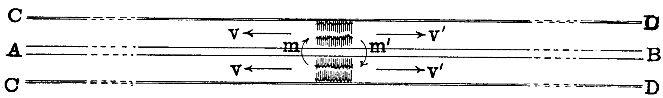


Fig. 27

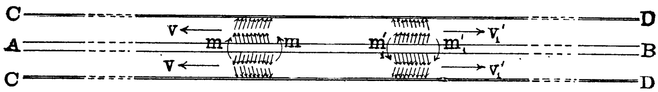
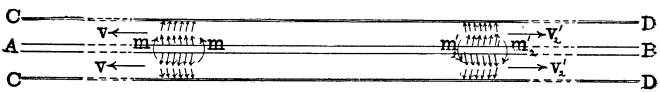


Fig. 28



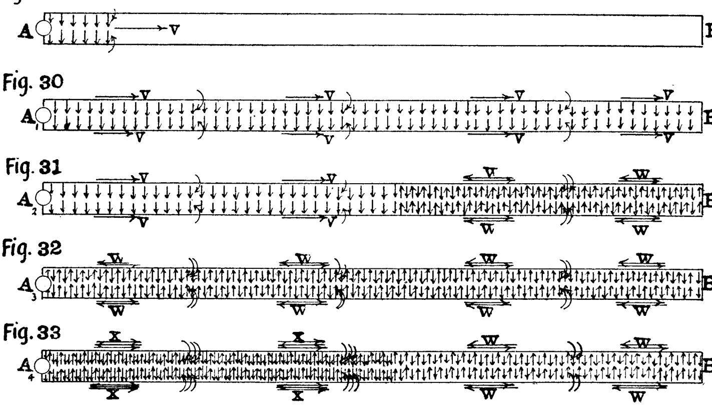
FIGS. 26–28.—Movement of Electric Flux in Distortionless Cable.

Fig. 28, represents the condition of attenuation without distortion at the later stage in the process.

We have hitherto assumed that only a metre block of electric flux was started from the centre of the circuit, and that this was called into existence in some special manner. We shall now consider what takes place when an electric source, such as a dynamo or battery, is connected permanently between the wires at one end of the circuit. In Fig. 29, a dynamo is supposed to be connected at the end A, the positive pole to the upper wire and the negative pole to the lower wire. The dynamo is assumed to have no resistance, and the distant end of the line is short-circuited at B. The moment the connection is effected, electric

flux is supplied from the dynamo to the insulating medium between the two wires. The rush of electric flux which escapes from the dynamo constitutes the electric current which it supplies, and if a certain imaginary unit quantity of electric flux constitutes a *coulomb of electricity* (the practical unit of electric quantity), then the number of coulombs of electric flux, uniformly supplied per second from the generator, represents the number of amperes of electric current supplied to the circuit. If the pressure of the generator is 1000 volts, then the difference of potential between the wires at A, is 1000 volts, and these two wires we may first assume to be per-

Fig. 29 Fig. 30 Fig. 31 Fig. 32 Fig. 33



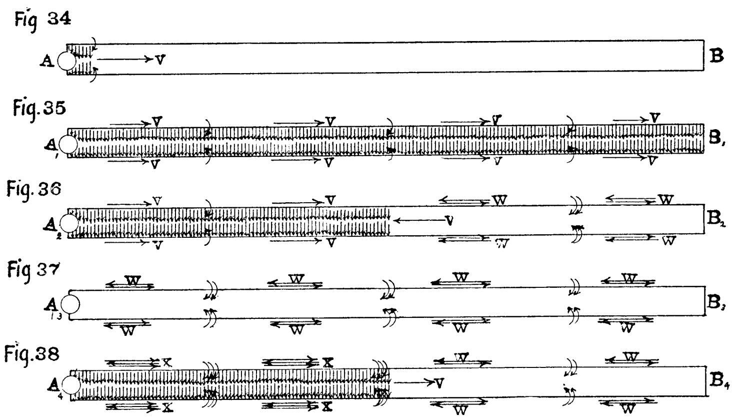
FIGS. 29–33.—Movement of Electric Flux in Closed Circuit of Perfect Conduction and Insulation, when Supplied by a Generator of no Resistance at One End.

fectly conducting. The arrow v, in Fig. 29, represents the initial direction of flux rush, from A towards B. As the flux moves along towards B, with the velocity of light, more flux comes out of the generator. The function of the generator is to supply flux to the insulating medium with which it is connected by the wires. The curved arrows represent the direction of the magnetic flux distribution which everywhere accompanies the moving electric flux.

Fig. 30, represents what takes place by the time that the vanguard of electric and magnetic fluxes has reached the end B. The entire insulator between the two wires is now full of electric flux at the particular density furnished by the dynamo at its pressure. With perfect conduction and perfect insulation there has been no loss of energy, and the magnetic flux and electric flux are just as

dense at B, as they are at A. Reflection with reversal of electric flux takes place at the short-circuit under B_1, so that, as shown in Fig. 31, the vanguard of electric flux can rush back towards A_2, after reflection from B_2, and having the direction represented by the upward arrows, so that, at and near B_2, as much electric flux is now pointing downwards as pointing upwards. There is, consequently, no resultant electric flux near B_2, although there is twice as much electric flux, considered without regard to direction. The magnetic flux is, however, doubled as determined by the reasoning accompanying Fig. 15.

After the proper interval of time has elapsed, the vanguard of electric flux has arrived at A_2, while further flux is all the time pouring out of the dynamo; this condition is represented in Fig 32. It again reflects at A_3, with reversal of electric flux, and advances once more towards B_4, Fig. 33, in the original direction, so that there are now two streams of downwardly directed electric flux, and one stream of upwardly directed flux, leaving as a resultant a single stream, but the magnetic flux is trebled in density. The resulting



FIGS. 34–38.—Movement of Electric Flux in Closed Circuit of Perfect Conduction and Insulation when Supplied by a Generator of no Resistance at One End.

condition is represented in Figs. 34 to 38, which correspond respectively to Figs. 29 to 33. In the first passage between A_1 and B_1, the electric flux fills the entire insulator. In the next passage between A_3 and B_3, Fig. 37, the electric flux entirely vanishes by a process of cancellation of oppositely directed streams, but the mag-

netic flux is doubled. In the third passage from A_4 to B_4, Fig. 38, there is a reappearance of the original electric flux and potential, but with the magnetic flux trebled. In the fourth passage, not shown, there is a disappearance of electric flux with the magnetic flux quadrupled, and so on indefinitely. The current strength, which is always measured by the density of magnetic flux, continually increases by successive leaps at each succeeding passage, but the electric difference of potential between the wires oscillates between the original quantity of 1000 volts and zero. After an indefinitely long period from the start, the current carried by the circuit will be indefinitely great, and this corresponds to what Ohm's law would prescribe in a case of perfect conduction.

Any actual circuit of perfect insulation but imperfect conduction would differ from this case in the fact that the vanguard would be continually subjected to attenuation and distortion, so that it becomes less and less observable in its passage at each successive traverse of the circuit. Finally, after a certain interval of time has elapsed, no further accretion of electric or magnetic flux is perceptible. The rate of dissipation of energy taking place into the conductor, all along the circuit, would then be just balanced by the rate at which further flux energy is pouring into the circuit from the generator. This is the condition which is determined by Ohm's law for the case of a definite resistance and perfect insulation. The effect is to lower the pressure to zero at the distant end of the circuit, and to maintain a uniform strength of magnetic flux distribution all through the circuit. Consequently, when the steady state has been attained under the influence of imperfect conduction and perfect insulation, the potential falls steadily from the source towards the distant end, but the magnetic flux-rush is constant throughout. The electric flux-rush is, therefore, also constant at all parts of the circuit, but some of the rush is directed upwards and some of it is directed downwards, so that at the distant end there is no resultant electric flux, while at the generator end the resultant electric flux is at full density.

This condition is represented in Fig. 39. Here the outrush from the dynamo is indicated by the long flux arrows pointing downwards. As these reach the BD end of the circuit, they are shortened in length, to indicate that the flux density has suffered diminution by attenuation on the journey. The reflected stream is then shown by the reversed arrows, which shorten in length as they return

to the generating end. These are again reflected with reversal, and the shortening process continues from end to end until the stream is no longer perceptible. The contrary movement of the tailings is omitted, for convenience, from the diagram. At E_1, these various stages of the stream are indicated by the horizontal arrows. The first is a long arrow e_1, representing the outgoing stream of full strength. Then come a pair of oppositely directed arrows indicating the passage of the stream on return to AC, with reflection therefrom; then similar pairs of oppositely directed arrows for succeeding returns of the stream, each time weaker and weaker, until finally no longer perceptible. The sum of all these is the first arrow e_1, since all the rest are in pairs which cancel. Consequently, the electric flux at E, has the resultant e_1, or the full strength and density of issue from the dynamo, as shown at E'_1, which represents the voltage or potential difference between the wires at E_1. If the voltage of D, is 1000 volts, E'_1, is 500 volts positive, and E''_1, 500 volts negative.

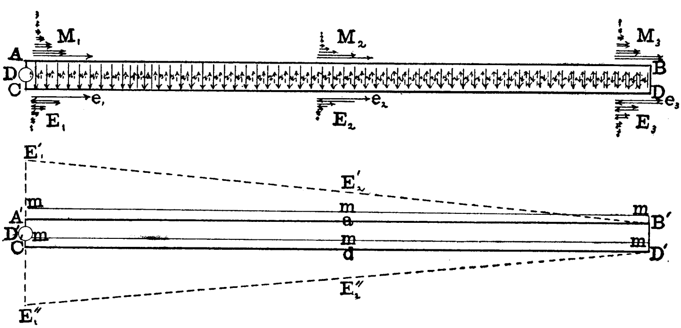


FIG. 39.—Distribution of Electric Flux Streams in Conformity with Ohm's Law in a Perfectly Insulated Closed-Circuit.

Again at the BD end, the electric flux streams are indicated at E_3. First come two opposite arrows e_3, representing the first arrival of the stream and its immediate reflection with reversal. Then follow successive pairs of oppositely directed shortened arrows. The sum of all these is clearly zero, so that the resultant flux density at BD, is zero, and there is no resultant voltage or potential difference. At B′D′, therefore, the dotted lines indicating potential fall to zero or join the lines A′B′ C′D′.

Again, in the middle of the line at E_2, there is a series of succes-

sive arrows, none of which entirely cancel. Their sum, however, is half e_1, and at ad, the voltage E'_2, E''_2, falls on the dotted lines E'_1 B', E''_1 D'. The same is true for any other point on the line. Consequently, the pressure falls steadily from AC to BD.

It is otherwise, however, with the magnetic flux which undergoes no reversal. The development of this is shown at M_1, M_2 and M_3. The arrows are all of equal length to the corresponding electric flux arrows at E_1, E_2 and E_3, but there is no reversal of direction. The sum of all these sets of arrows is constant at all points of the line, and this condition of constancy in total magnetic flux is represented by the horizontal straight lines m, m, m, m, m, m. In other words, the current strength is constant.

The rate at which energy is being transferred from the dynamo along the circuit past any point is simply the sum of the electric and magnetic energies contained in the various passing streams of flux, the summation being made with regard to the direction of these streams. Thus the first stream may carry past the point considered 1,000,000 ergs in each second, half in magnetic energy, and half in electric energy, the second stream may carry 500,000 ergs backward, the third 250,000 forward, and so on; the resultant stream in this case being 666,667 ergs per second forward, and this is the activity of the circuit at the point considered.

According to these views, therefore, the electric current, which is electric flux-rush, is invariably transmitted with the velocity of light in the ether of the particular insulator considered. But the actual velocity with which an electric impulse travels along the circuit, as measured by the time which elapses between the connection of the source at the generating end and the appearance of energy at the receiving end, always tends to be less than this velocity, because, owing to attenuation and distortion, the first impulse or block of flux may be completely absorbed and dissipated before it can reach the distant end with the velocity at which it travels, and further flux must gradually come up from the source and suffer attenuation and distortion, before the vanguard can finally arrive at the receiving end and perform its allotted function. It is for this reason that a submarine electric cable between say Ireland and America, takes nearly $\frac{1}{7}$th of a second before an electric signal or impulse transmitted from one end will make its first appearance at the other, although the time that an electric wave would take to traverse its length would be only say about $\frac{1}{60}$th second. The original impulse

traveled so far as it went with the velocity of light in the ether of gutta-percha, but the vanguard was completely dissipated and the successive vanguards were attenuated with complete dissipation for a comparatively long time before the distant end could be reached.

It is only on long circuits, such as are afforded by telegraph and telephone wires or submarine cables, that the phenomena of electric transmission with their attendant distortion and attenuation are most clearly evidenced. In the comparatively short circuits employed for transmission of electric light and power, the phenomena of distortion and attenuation of electric and magnetic flux are of little practical importance. Fig. 40, represents the signals sent over

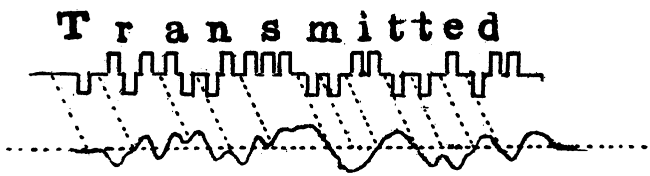


FIG. 40.—Distortion of Signals Received Over Last-Laid Atlantic Submarine Cable.

the last laid Atlantic cable and the corresponding signals which were received at the distant end. The two should be exact facsimiles and should, therefore, be capable of actual superposition if no distortion occurred in the electric impulses. Not only the delay or retardation in the received signals, but also the great distortion which is noticeable, are due entirely to the fact that there is very little leakage in the insulator, while there is very appreciable resistance in the conductor. This cable, laid in 1894, has a published length of 1847.5 nautical miles. The copper conductor offers a resistance of 1.68, or about $1\frac{2}{3}$, ohms per nautical mile, while the insulator has a resistance of 85,000,000,000 ohms in each nautical mile. This cable has a working speed of over forty-five words per minute, which is much faster than any other previously laid Atlantic cable, owing to the greater conductance of the circuit. This cable possesses, of course, enormous distortion, although such distortion does not prevent signals being read until a speed of over 225 letters per minute is attained. If, however, the insulation, instead of being 85,000,000,000 ohms in each nautical mile, were reduced to about 500 ohms in the nautical mile, the leakage tailings would

probably balance the tailings due to imperfect conductance and the cable would be distortionless. The signals received would, therefore, be the exact counterpart of the signals sent, and an indefinitely high speed of signaling should be possible. In respect to absence from distortion, such an Atlantic cable would transmit telephonic speech waves perfectly. It would, however, possess so much leakage that the received signals would be far too attenuated and feeble to perceive. The conductor would only offer at the sending end a resistance of, approximately, 28 ohms, instead of 3108 ohms, the total conductor resistance, and the current strength which would flow from the receiving end to ground would be, approximately, 5×10^{47} times less than the current entering at the generating end. No telegraphic or telephonic instrument at the present time could detect so feeble a current as this. Moreover, if any accident happened to such a cable it would be impossible to localize the position of the fault unless the same occurred within a mile or two of either end. Consequently, the distortionless circuit does not provide at the present time a practical solution for trans-Atlantic telephony. About one hundred miles is, probably, the limiting length of this particular cable, with its good insulation, over which telephonic speech can be carried.

We have not considered the mechanism whereby the electric and magnetic flux, when it reaches the receiving end, is absorbed and its energy utilized for the performance of any kind of work, such as the operation of a motor, the production of signals, or of articulate speech. It has been sufficient to point out that the electric current runs through the insulator from one end of the circuit to the other, and is guided by the two conductors, which with the insulator form the circuit. If it were not for these two conductors, any electric wave or impulse would radiate out into space in all directions, like light from an unprotected candle. The wires do for the electric wave what a reflector does for the search light; namely, localizes and concentrates the beam into a single path, whereby it may be transmitted to the desired point with the minimum attendant loss in transmission.

DISCUSSION.

MR. PAUL A. N. WINAND said:

I have been very kindly invited by the authors of the paper to participate in its discussion. I wish to express first my appreciation of the remarkably thorough, clear and original manner in which

they have accounted for the conditions which exist *in the space surrounding the conductor* in the phenomenon called electric current. In fact I could not attempt to add anything to this very clear exposition. I have therefore collected the objections that can be raised against some of the views and conclusions of the authors.

We first encounter a difficulty as long as we do not bear in mind the dual nature of the electric flux considered in relation to electrostatic conditions. The flux is to be taken, respecting one of its manifestations, as a measure of electric quantity inasmuch as, when rushing, each unit will produce the same magnetic flux, but this effect is independent of the difference of electric potential. The energy transferred is, however, proportional to this difference.

In the case represented by Fig. 39 of a perfectly insulated closed circuit, the quantity of flux, owing to the perfect insulation, must remain unchanged as it rushes along the line, but the other factor in the transfer of energy, due to the rush of flux, the difference of potential, decreases as the energy is transformed into heat in the conductor. If I understand the authors correctly, they consider the process as entailing a diminution of the first factor (quantity) by partial reflexions constituting the imperfect conduction, while the second factor remains unaltered. It is difficult to see how, with perfect insulation, at any point of the line, where such reflexions occur (the reflected fractions of flux returning towards the origin), energy will cease to be electric and become thermic, since the reflected fractions will carry their energy away undiminished from that point, while the unreflected part of the flux will carry its share away in the primary direction of main rush.

As to the view held by the authors that the electric current runs through the insulator, or, more broadly, through the space outside the conductor, and is merely guided or localized by the latter, it seems to me open to some grave objections. It is true that the old view, which considered the conductor as the only real seat of the phenomenon, is not tenable. But there is another intermediate position, which has been expounded by Poynting, Lodge, J. J. Thomson and others, which is: that while the current flows through the conductor, the energy, which is generally transferred simultaneously, travels through the space surrounding the conductor.

As stated by Lodge: "We must learn then to distinguish between the flow of electricity and the flow of electric energy; they do not occur along the same paths. . . . . Electric energy is not

to be regarded as pumped in at one end of a conducting wire and as exuding in equal quantities at the other. The electricity does indeed travel thus, whatever the travel of electricity may ultimately be found to mean, but the energy does not." Poynting expresses it thus: "Formerly a current was regarded as something traveling along a conductor. But the existence of induced currents and of electromagnetic action at a distance from a primary circuit, from which they draw their energy, has led us, under the guidance of Faraday and Maxwell, to look upon the medium surrounding the conductor as playing a very important part in the development of the phenomena."

I am not prepared to abandon this intermediate point of view for the reasons which I shall presently state. It naturally depends to a great extent on what we are to understand by an electric current. The nature of electricity being unknown, this phenomenon can only be dealt with as a sum of correlated effects. Some of these occur in the conductor, some in the space outside of it.

One fundamental relation was obtained when it was proved by experiment that the translatory motion of a charged conductor produced the external effects of a current; the effects otherwise found in the conductor being then absent because the conductor moved with the charge and with its external condition or electric flux.

It might be argued that the conducting body, say a charged sphere, should be considered as being mainly a discontinuity in the surrounding insulating space and that the displacement of this discontinuity created the effects by disturbing the space. The experiments of Rowland, however, have established that a rotary motion of a plane conducting disc around its axis produced the same external effects as a current and in this case the conductor, considered as a discontinuity in the insulating space, did not change its position. Does this not tend to show that the unknown condition which moves bodily with the substance of the conductor in the one case moves along the conductor in the other case, which is called current proper?

On the other hand we find that in the case of current proper, effects are produced within the conductor, and we find also that these effects occur not merely at the boundary between conductor and surrounding space, but throughout the cross-section of the conductor. This is undoubtedly true of the heating, the electrolytic effects, osmotic effects, migration of the ions, actions at the

electrodes, some luminous effects (as in gases), thermo-electric effects broadly and of some magnetic effects. It is an established fact that when a conductor carries a so-called current the magnetic lines of force or flux do not exist only in the space around it, but they are present also within the cross-section of the conductor. Their density is, however, smaller at points inside the cross-section than at points immediately outside of it and at the centre of a circular homogeneous cross-section this density is equal to zero. Does this not clearly point to the conclusion that the action which produces the field in the surrounding space has its seat in the cross section of the conductor and extends throughout the same?

Even for effects such as those of so-called free static electricity which seem clearly to have their seat at the boundary between the conductor and the space surrounding it, can we disregard the conductor which is an essential part of the apparatus, though the effects so far discovered in such cases seem to reside in the surrounding space?

Turning now from the consideration of continuous currents to that of very rapidly alternating or freely alternating currents which generate waves of electromagnetic disturbance in space, as first demonstrated by Hertz, we find that, on connecting the charged conducting bodies, the disturbance originates on these bodies and gradually spreads into space with the velocity of light. The phenomenon starts with a current having its seat on the conducting bodies and the surrounding space is affected subsequently, as by light emanating from a spark. Is it then not natural to consider the conductor as the seat of the current and as the primary factor in the apparatus?

In view of these considerations, I cannot but retain the point of view stated above, though I am ready to admit that, as the changes of distribution of energy take place through the surrounding space, the latter may be considered as more important than the conductor. It should not be forgotten, however, that we can only postulate but not demonstrate the travel of energy, while we can measure its disappearance at one point and its appearance at another. We can only find changes in the distribution of energy. Now if we consider a conducting circuit of inappreciably small resistance; a current of any strength can be existent without a comparatively appreciable change in the distribution of energy, which shows that even the practical importance of this action is not always evident.

Dr. A. Macfarlane: I wish first of all to express my sense of the admirable manner in which the authors have carried out the aim which they set before themselves. Behind their description of the manner in which an electric current is now believed to be transmitted there is a great amount of mathematical analysis and experimental verification.

In a work on the *Applications of Electricity*, written by Count du Moncel before the beginning of the great industrial development of electricity, he refers to a fanciful plan of a M. Charles Bourseul for transmitting speech by electricity. The Count makes great fun of the idea; yet he lived to write a book on the telephone. What struck him as especially absurd was that vibrations produced by the human voice could be thought capable of transmission through a solid wire of copper. And indeed it is wonderful how electricians have been so long content to regard the current of electricity as transmitted by the copper molecules, or even by the ether in the wire between the molecules.

In the study of electrotechnics there is nothing more important than clear ideas about the relation of the electric current to the associated magnetic flux. It is important to observe that there are many analogies between the two; but it is also important to observe that the analogy is not complete. The electric current involves in its idea the element of time in a way that the magnetic flux does not. Now observe how the theory expounded explains this. We have the complementary ideas of electric flux and of magnetic flux and also the other two ideas of rush of electric flux and rush of magnetic flux; the electric current in general meaning motion of the combined flux.

For some time it was customary to neglect the study of static electricity because its connection with current electricity was not evident. But observe that the one idea—electric flux—comes from the old science of static electricity, and the other idea—magnetic flux—from the old science of magnetism: together they explain the phenomena of the flow of electricity along a conductor.

In the text-book of *Electricity and Magnetism* which I studied there was an article headed "Velocity of Electricity." Account was given of some experiments made to determine the time required for the transmission of signals along conducting lines; the disagreement of the values obtained was pointed out, and the writer concluded that properly speaking there was no such thing as the

velocity of electricity. But observe how the theory expounded rests on that very idea, how it explains all the seeming contradictions, and shows what in certain cases reduces the velocity of electricity from that of the velocity of light in the ether.

Stated Meeting, April 2, 1897.

Vice-President, Dr. PEPPER, in the Chair.

Present, 45 members.

Correspondence was submitted.

Mr. Pettit, on behalf of the Curators, presented a report, recommending that the North Room be fitted up for the use of the Cabinet.

Dr. Pepper presented the report of the Special Committee on the Needs of the Library.

The following resolutions were then adopted :

1. That the immediate needs of the Library demand that the North Room be devoted to its purposes.
2. That the Peale Collection be maintained in the North Room for the present.
3. That the collections of plants be transferred in trust as a deposit, subject to recall, to such institution as may be ordered by the Society.
4. That the duplicate collection of rocks be submitted to a Committee of Geologists (Messrs. Lyman, Prime, Frazer and Platt), to report to the Society their recommendation as to its disposition.
5. That a Special Committee of nine (Dr. Pepper, Messrs. Harris, Pettit, T. H. Bache, Price, Frazer, Stone, Jos. M. Wilson and Hays) be appointed to adopt plans for the adaptation of the North Room for the above purposes and to make suitable provision for the other objects of the Society, and that the Hall Committee be empowered to expend a sum not exceeding one thousand dollars in carrying into effect the plans so adopted.

A letter from Judge Mitchell on behalf of the Commission to collect and print the Statutes at Large of Pennsylvania, from the foundation of the colony to the year 1800, asking that the Society grant it the privilege of using a volume of